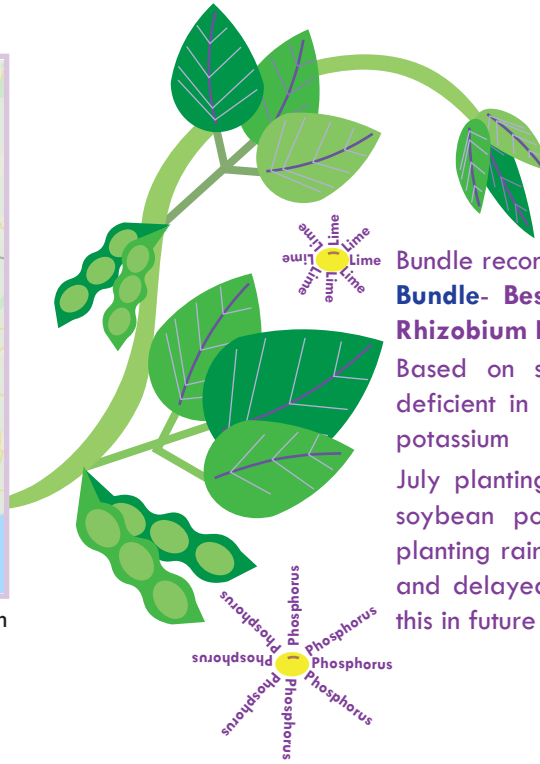


In partnership with the Soybean Innovation Lab (SIL), Horizon Farm Limited. conducted SMART (Soybean Management with Appropriate Research and Technology) Farm input omission trials at a single location in Lisungwi, Malawi (Figure 1, Table 1).



Figure 1: Horizon trial location for 2020 season



Summary

Bundle recommendation for the Lisungwi field site: **Blue Bundle- Best Management Practices, Certified Seed, Rhizobium Inoculum, Lime**

Based on soil fertility results, the Lisungwi site is deficient in Phosphorus, and dufficient in soil pH and potassium

July planting of the 2020 irrigated trials resulted in soybean pod maturity coinciding with the Summer planting rains in December. This delayed grain drying, and delayed harvest. Planting in late May will avoid this in future trials.

The input omission trials at both locations were composed of 16 treatment combinations (Table 2) of phosphorus, potassium, lime, and inoculant (Table 3). Each set of 16 treatments were randomized and replicated 4 times. The soybean variety “Serenade” was planted in 5 meter by 3 meter plots with a seed spacing of 5cm. Each plot contained 4 rows with a spacing of 75 cm. Seeds were treated with Hi-Stick rhizobia inoculant 1 hour prior to planting. Calciprill lime was applied in the seed furrow at planting. Approximately 21 days after germination at the V2 or V3 developmental stage, single super phosphate and muriate of potash were applied to treated plots as a side-dress 5 centimeters from the furrow, and 5 centimeters deep. The field site was watered using sprinkler-irrigation throughout the season.

Treatment	L	I	P	K	S
1					+
2		+			+
3			+		+
4				+	+
5		+	+		+
6		+		+	+
7			+	+	+
8		+	+	+	+
9	+				+
10	+	+			+
11	+		+		+
12	+			+	+
13	+	+	+		+
14	+	+		+	+
15	+		+	+	+
16	+	+	+	+	+

Table 2: Treatment combinations for the Omission trial. L=Lime, I=Inoculum, P=Phosphorus, K=Potassium, S=Seeds.

Country	Location	Planting Date	Harvest Date	Latitude	Longitude	Elevation
Malawi	Lisungwi	7/9/2020	1/5/2020	-14.216667 S	33.7 E	1156

Table 1: Site information for the Horizon omission trial, including planting and harvest date. Dates are written as: month/day/year.

	Phosphorus	Potassium	Inoculum	Lime	Seed
Product	Single Super Phosphate	Muriate of Potash	Hi Stick	Calciprill	Serenade
Source	-	-	BASF	OMYA	Seed Co.
Concentration	P2O5-13%	K2O-60%	-	CaO-36%	-
Appication Rate	75kg ai/ha	75kg ai/ha	400g/100kg	300kg/ha	320000 seed/ha

Table 3: The product names, sources, concentrations and application rates of inputs used for the omission trial. kg ai/ha – Kilograms of active ingredient per hectare.



Figure 2: Lisungwi field location. The top-left image shows field preparation (Photo taken July 9, 2020). The top-right image depicts healthy, but delayed soybean growth at 76 days after planting. Sprinkler irrigation shown (photo taken September 23, 2020). The bottom image shows delayed soybean maturity at 151 days after planting (Photo taken December 7, 2020).

Month	Max Temperature (°C)	Min Temperature (°C)	Rainfall (mm)
June	23.9	13.0	0
July	23.0	11.9	0
August	26.8	13.8	0
September	28.8	16.4	0
October	30.9	19.3	17.7
November	33.0	21.2	33.3
December	29.1	19.9	187.3

Table 4: Monthly averages for maximum and minimum temperatures and the total monthly rainfall for 2020 season at the Lisungwi site. This does not include water applied through irrigation.

Seasonal temperature and precipitation information for the field site is displayed in **Table 4**. Temperatures peaked in November reaching 33.0°C with a minimum temperature of 11.9°C occurring in July. Between the months of June 2020 and December 2020 the total observed rainfall was 238.3mm. Supplemental irrigation was applied each day as approximated in **Table 6**. During this trial soybean maturity was delayed from the expected 90-120 days after planting to 187 days. Two potential reasons for this delay are the shift in photoperiod and reduced temperatures due to planting during the winter season. Irrigated 2020 winter season trials were planted in July, which resulted in soybean pod maturity coinciding with the 2020-2021 summer season planting rains in December. This delayed grain drying, and delayed harvest. Ensuring irrigated winter season trials are planted in late May will avoid this situation in future trials.

Test	Method	Units	Lisungwi
Soil pH	1:1 - Water pH	-	6.4
Phosphorus (P)	Mehlich 3	ppm	9
Potassium (K)	Mehlich 3	ppm	171
Calcium (Ca)	Mehlich 3	ppm	3277
Magnesium (Mg)	Mehlich 3	ppm	710
Sulfur (S)	Mehlich 3	ppm	39
Boron (B)	Mehlich 3	ppm	0.22
Copper (Cu)	Mehlich 3	ppm	4.4
Iron (Fe)	Mehlich 3	ppm	216
Manganese (Mn)	Mehlich 3	ppm	204
Zinc (Zn)	Mehlich 3	ppm	2.62
Sodium (Na)	Mehlich 3	ppm	82
Organic Matter	Loss On Ignition	%	6.45

Table 5: Soil fertility results for the Lisungwi site generated from Brookside Laboratories. Soil nutrient amounts are displayed in parts-per-million (mg/kg).

Soil properties for the Lisungwi site are shown in Table 5. The field site had a sandy clay texture. The soil has a pH of 6.4. Optimal soil pH for soybean ranges from 6.5-7.0, so no additional liming would be recommended for this site. Potassium levels are well above the threshold (110mg/kg) for sufficient soybean production and no potassium amendments are required. Soil phosphorus levels are shown to be below our 30 mg/kg threshold for sufficient soybean production and would benefit from in-field fertilizer application.

Growth Stage	Days after planting	Millimeters of water per day
Germination and Seedling	1-20	2.5
Vegetative growth (V2 up to flowering)	20-30	5
Bloom (R1-R2)	30-40	5
Early pod development (R3)	50-60	5
Pod-elongation (R4)	65-75	6
Seed development and fill (R5-R6)	75-105	7
Pod color change (R7)	102-116	5
Maturity (R8)*	113-130	1
Estimated seasonal irrigation	455-500mm	

Table 6: Approximate rates of irrigation. *Once plants reach full maturity (R8), irrigation ends.

Data collection metrics for the input omission trial are described in **Table 7**. Stand count was measured at V2 and R8 developmental stages. Plant height was measured at R1 and R8 developmental stages. Measurements for nodule count, weight, and viability were measured at the R3 developmental stage.

Trait	Unit	Measurement Metrics
Stand Count	count	Sum of plants in Row 2 and 3
Days to Flowering	days	Days after planting when the first flower is observed
Plant Height	centimeter	Distance from soil to the Shoot Apical Meristem on main stem
Nodule Count	count	Number of Rhizobium nodules on roots collected at R3-pod filling stage
Nodule Weight	gram	Mass of Rhizobium nodules on roots collected at R3-pod filling stage
Nodule Viability	%	Percentage of counted nodules that are active and viable
Yield	ton/hectare	Plants harvested and threshed, seed winnowed and weighed at 13% moisture
100 seed weight	gram	Random sets of 100 seeds selected and weighed

Table 6: Data metrics for the 2020 SMART Farm omission trials

Treatment	Rank	Yield	V2 Stand	R1	R1	Nodule	R8 Stand	R8	100 seed
	Yield	Yield	Count	Flowering	Height	Count	Count	Height	Weight
		ton/ha	count	days	cm	count	count	cm	g
P+K	1	3.50	148	78	62	19	122	115	29.3
L+K	2	3.37	155	80	54	16	141	102	29.3
L+I	3	3.37	150	79	58	25	128	117	29.0
L+I+P+K (**)	4	3.20	151	79	56	23	138	108	29.0
K (.)	5	3.03	141	77	53	23	132	104	27.8
I+K (**)	6	2.90	159	77	57	28	136	105	27.3
L+P+K	7	2.83	143	78	52	20	131	104	27.3
L+P	8	2.80	150	77	58	19	124	110	29.0
L+I+P	9	2.77	149	77	53	16	140	98	30.3
I+P	10	2.70	145	78	45	17	146	91	30.0
P	11	2.40	151	78	44	20	125	92	28.5
I+P+K	12	2.37	158	77	47	14	140	93	27.5
I	13	2.30	167	78	53	16	116	97	27.5
L	14	2.07	151	77	52	17	129	96	27.5
No Input	15	2.03	162	77	41	14	105	84	27.5
L+I+K	16	1.83	148	77	54	25	140	106	28.5
AVG		2.72	151.6	77.5	52.4	19.4	130.8	101.3	28.4
LSD (0.05)		1.09	28.1	1.9	16.0	14.8	27.3	26.8	3.2
CV%		30.77	12.2	1.8	21.5	51.4	15.1	18.4	7.8

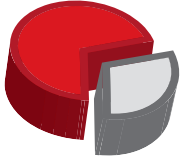
Table 8: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for Yield, Stand Count, R1 Flowering, Height, Nodule Count, Nodule Weight, 100 Seed Weight, and Seed Moisture for the 2020 omission trials at Lisungwi, Malawi. In the treatment column: I-Inoculum, P-Phosphorus, K-Potassium, L-Lime. P-values for each treatment main-effect or interaction are represented as follows: (.)>0.10, (*)>0.05, (**)>0.01, (***)>0.001

An Analysis of Variance (ANOVA) was conducted in R using the package “car” to test the main treatment effects, 2-way, 3-way, and 4-way treatment interactions in the omission trial. The Shapiro's Wile and Brown-Forsythe test were employed to confirm residual normality and homogeneity of variance respectively. Based on the ANOVA, **the main-effect of potassium, while not statistically significant (P-value 0.09), is linked to increased soybean grain yields.** The 2-way interaction between inoculum and potassium (P-value 0.007) and the 4-way interaction between all inputs (P-value 0.007) shown negative effects on yield.

Mean yields ranged from 1.83 tons/ha (L+I+K) to 3.50 tons/ha (P+K). Stand count ranged from 141 to 167 and 105 to 146 at V2 and R8 developmental stages, respectively. R1 flowering occurred between 77 and 80 days after planting. For reference, R1 flowering occurred at 46 days after planting during the 2019-2020 Summer season at Lisungwi. For plant height, all treatments lay between 41 and 62cm, and 84 and 117cm at R1 flowering and R8 developmental stages, respectively. Mean values for 100-seed weight ranged from 27.3g to 30.3g. Nodule count did not show a strong treatment effect in connection to inoculum usage. Nodule count ranged from 14 to 28 nodules. Nodule viability (data not shown) was low across all treatments with most nodules proving non-viable. This trial provides information on which inputs are best suited to maximize soybean yield and are a valuable resource for developing an input bundle approach to soybean production.

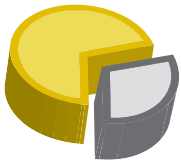
For further information on the 2020 trials at Lisungwi with Horizon, contact the trial operator Andrew Goodman, at kanyantandrew@gmail.com

Red Bundle



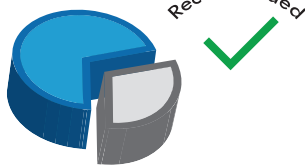
Best Management Practices
 Certified Seed
 9x return on input costs
 compared to farmer practice
Marginal Ratio: 3.2*

Yellow Bundle



Best Management Practices
 Certified Seed
 Potassium
 6x return on additional input
 costs compared to Red Bundle
Marginal Ratio: 1.5**

Blue Bundle



Best Management Practices
 Certified Seed
 Lime
 Inoculum
 9x return on additional input
 costs compared to Red Bundle
Marginal Ratio: 1.8**

*Marginal Ratio compared to farmer practices

**Marginal Ratio compared to Red Bundle

¹gross margin=revenue – variable costs

²Van Vugt, D., Franke, A. C., & Giller, K. E. (2017). Participatory research to close the soybean yield gap on smallholder farms in Malawi. *Experimental Agriculture*, 53(3), 396-415.

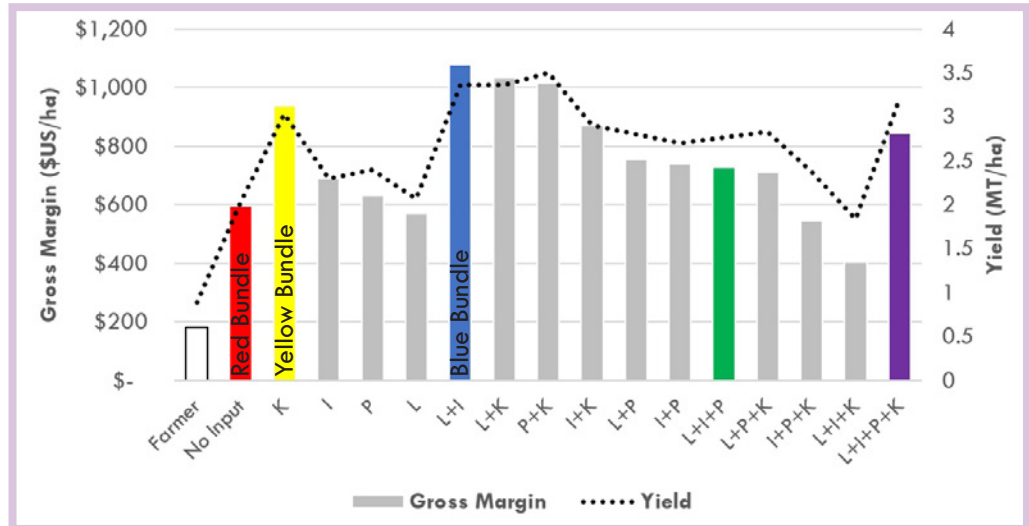


Figure 3: Treatment yields (line graph) and gross margins (bar graph)

Agricultural inputs such as lime, inoculum, phosphorus and potassium contribute to increases in soybean yield. However, the combination of specific field conditions and a farmer's limited cash funds may make using all four inputs either unnecessary or financially impractical. The 2020 SMART Farm omission trial has assessed the usage of these inputs and has assembled three input bundles for the Lisungwi field site. To balance the financial risk of applying new inputs, SIL recommends a stepwise investment in new technology. This prioritizes the maximum financial returns on the minimum input costs, and allows initial successes to feed into additional future inputs.

The gross margins¹ and yield averages are displayed in **Figure 3**. The "Farmer" treatment represents typical soybean farming practices in Malawi. It is assumed that saved seed is used with no additional inputs, and that labor costs are absorbed by the household². Under these conditions it is estimated that a typical farmer will generate a gross margin of \$182 USD and a yield of 0.82MT per hectare laboring between 60 and 70 work days in a season. This generates an implicit wage of \$1.05 USD for every \$1.00 USD of labor spent.

The Red Bundle is the standard growing package. This includes the usage of certified soybean seeds and the adoption of best management practices (early planting, planting in rows, increased seed population, and timely weeding). The Red Bundle in Lisungwi generated an average gross margin of \$596 USD, a marginal ratio increase of 3.2 compared to typical farming practices, and yielded 2.03MT per hectare. This produces a 9x return on seed costs and provides an implicit wage of \$3.44 USD for every \$1.00 USD of labor spent (a 244% increase in wages compared to the typical farmer).

A step up from the Red Bundle with the inclusion of potassium fertilizer, the **Yellow Bundle** generated an average gross margin of \$937 USD, a marginal ratio increase of 1.5 compared to the Red Bundle, and yielded 3.03MT per hectare. This produces a 6x return on potassium fertilizer costs and provides an implicit wage of \$5.42 USD for every \$1.00 USD of labor spent (a 442% increase in wages compared to the typical farmer). This yield increase due to potassium fertilizer is notable. While the trial ANOVA demonstrated a small positive treatment effect of potassium on yield, the soil fertility analysis indicated that potassium soil fertility at Lisungwi was sufficient. Equally notable is the lack of phosphorus impact on yield. Soil fertility shows that the Lisungwi site is deficient in phosphorus, but phosphorus treatments did not show a significant boost to yields.

The Blue Bundle is recommended for the Lisungwi site. The **Blue Bundle**, including inoculum, and lime, generated yields of 3.37MT per hectare and a gross margin of \$1,077 USD, the highest among observed treatments. This produces a 9x return on inoculum and lime costs and provides an implicit wage of \$6.23 USD for every \$1.00 USD of labor spent (a 523% increase in wages compared to the typical farmer).

Economic Assumptions

- For the typical Southern African farmer it is assumed that soybean seeds are saved from one year to the next, and that no additional inputs are purchased.
- A season of labor is estimated to be 60-70 workdays (472-560 hours) from land preparation to harvest. It is assumed that for a given household any necessary field labor will be conducted by members of that household.
- Fixed costs such as leasing costs for land, property tax, insurance, managerial overhead, or transportation costs are not included in the variable cost estimates. It is assumed that these costs are consistent across treatments.
- It is assumed that the labor involved in applying different input treatments is equal.
- It is assumed that local African soybean prices are linked to and stabilized by world-wide soybean prices.

Definitions

Gross Margin: For the SMART Farm reports, SIL defines the Gross Margin as the variable costs of soybean production minus the revenue generated from seed sales.

Marginal Ratio: The quotient between two gross margin values.

Return on Input Costs: The return on input costs compares how much was spent on inputs to how much additional monetary value that input provides.

Values for Economic Analysis

Item	\$ USD/ Hectare	Source
Input Costs		
Certified Soybean Seed	\$44.40	1
Rhizobium Inoculum	\$14.13	2
Phosphorus Fertilizer	\$109.00	3
Potassium Fertilizer	\$58.14	4
Lime	\$37.25	5
Labor Costs		
Labor (Land preparation, planting, weeding, harvest, bagging)	\$173.01	6
Soybean Selling Price		
Item	\$USD/ Kg of Seed	Source
Seed Price	\$0.40 (\$400.00/MT)	7

*Costs and prices are average values aggregated from multiple sources

Source

- 1) Internal SIL communications, Analysis of the Soya Bean Value Chain in Zambia's Eastern Province (2012), Soybean Value Chain-AECOM International Development (2011), IAPRI-soybean value chain and market analysis -Zambia (2014), Profitability and technical efficiency of soybean production in northern Nigeria (2017), Income and Cost Budgets for summer crops in South Africa- (2018-2019), Soybean Production Guide In Uganda (2015)
- 2) Internal SIL communications, IAPRI-soybean value chain and market analysis -Zambia (2014), N2F-Production and use of Rhizobial inoculants in Africa (2011)
- 3) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019), South African Fertilizer Market Analysis Report (2018), Agricultural Prices, USDA, National Agricultural Statistics Service (2020), Spatial variation in fertilizer prices in Sub-Saharan Africa (2020)
- 4) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019), South African Fertilizer Market Analysis Report (2018), Agricultural Prices, USDA, National Agricultural Statistics Service (2020), Spatial variation in fertilizer prices in Sub-Saharan Africa (2020)
- 5) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019)
- 6) Internal SIL communications, Soybean Costs of Production-(2019), Soybean Value Chain-AECOM International Development (2011), IAPRI-soybean value chain and market analysis -Zambia (2014), Profitability and technical efficiency of soybean production in northern Nigeria (2017), Soybean Production Guide In Uganda (2015)
- 7) Internal SIL communications, www.selinawamucii.com (2020), Soybean Prices (2019), Zambia National Farmers Union (2020), USDA Market News (2020)